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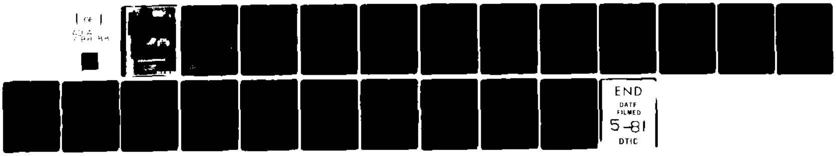

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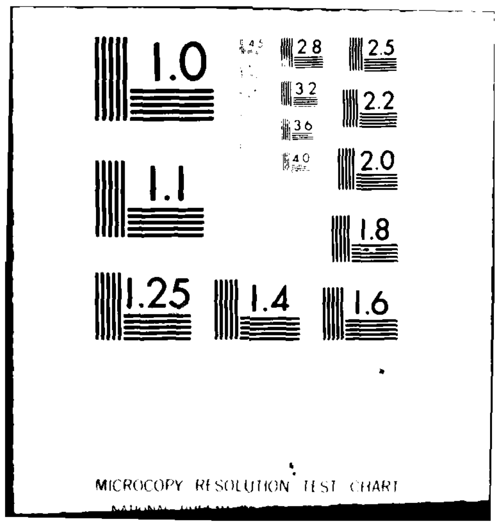
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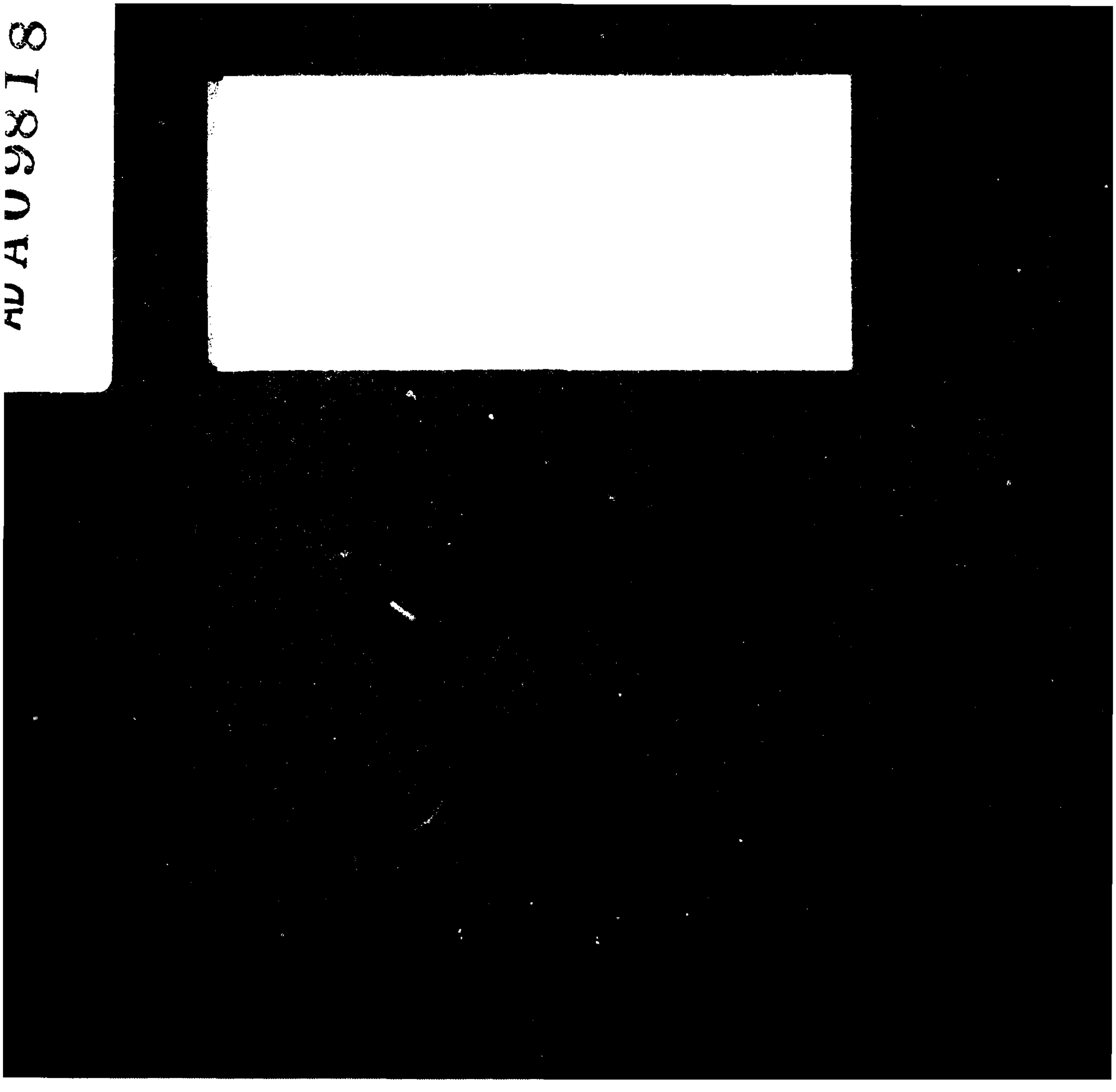

LEVEL II

SHEAR DATA DESCRIPTIONS

PROGRESS REPORT I

SAI 81-240-WA

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SHEAR DATA DESCRIPTIONS.
PROGRESS REPORT, I

SAI-81-240-WA

Contract #N00014-80-C-0393

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ABSTRACT

Five data sets are described with reference to their utility for describing upper ocean shear. These are free fall profiler data sets from YVETTE and SCIMP; Tracked Drogues, Acoustic Doppler Sonar, and Expendable Current Profilers. Data from the free fall profilers are being examined by SAI investigators. This report is the first of four progress reports describing the joint use of these data by SAI and NRL.

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Section 1
INTRODUCTION

Personnel from Science Applications, Inc. (SAI) and the Naval Research Laboratory (NRL) are working jointly on a description of shear in the upper ocean. SAI is focusing on vertical variability of vertical shear based on data obtained from free-fall velocity profilers. NRL is focusing on horizontal variability of both vertical and horizontal shear based on Lagrangian drifters. Another NRL data set resulting from simultaneous measurements with a Doppler sonar instrument and expendable current profilers will be described, but may not be processed in time for inclusion in this project. The purpose of this project is to assess the utility of combining the horizontal and vertical descriptions into a more comprehensive picture of upper ocean shear. Particular emphasis is to be placed on the distribution of Richardson number. The purpose of this progress report is to briefly describe the range of applicability of each data set and outline ways in which they may be related.

Section 2
THE DATA SETS

2.1 VERTICAL PROFILES

The data sets being examined by SAI have been presented in Lambert, Evans, and Hendricks (1980) and the response of the two profilers involved, YVETTE and SCIMP will be compared by Lambert, Rubenstein, and Newman (1980). Both profilers fall freely through the water and measure conductivity, temperature, and two horizontal components of velocity versus pressure. YVETTE, which is a cylindrical body four meters long, falls through the water at approximately 25 cm s^{-1} and records data at a rate of 2.5 samples per second to yield a vertical sampling interval of 10 cm. SCIMP is a much less streamlined sensor package whose frame is approximately 7 ft (2.1 m) long, 1.5 ft (.5 m) wide, and 2.5 ft (.8 m) high. In the initial part of the descent of SCIMP, the instrument drops at a rate of approximately 25 cm s^{-1} until the desired sampling depth is reached. Then a weight is jettisoned and the descent rate slows to its normal value of approximately 12 cm s^{-1}. Measurements are recorded at a rate of 5 samples per second to yield a vertical resolution of approximately 2.4 cm. In the case of both profilers, the data from the upper 10-50 m are lost while initial transients damp out.

The trajectory of both profilers is affected to some extent by the horizontal drag imposed on the instrument package by the large scale vertical shear. In the case of both instruments the velocity actually measured is the

relative horizontal velocity between the profiler and the water. Since YVETTE is longer and descends at a faster rate than SCIMP, it is capable of directly measuring velocity variations over larger vertical scales (up to 20 m for YVETTE as opposed to 5 m for SCIMP). In addition the effects of drag on the profilers can be modeled well enough to extend the effective range of YVETTE to vertical scales of approximately 100 m and that of SCIMP to approximately 30 m. Hence, after the data are filtered, smoothed and corrected for horizontal drag effects, YVETTE can resolve vertical velocity gradients over scales between 2 m and 100 m while SCIMP can resolve gradients over scales between .2 m and 30 m. The data could be degraded to provide estimates of gradients over larger vertical scales, but shears estimated in this way would probably be too low.

Since free-fall instruments measure the variations in properties along their trajectories, which are essentially vertical, these devices are inherently best suited to an examination of quantities defined in terms of vertical gradients such as vertical shear, Brunt-Väisälä frequency, and Richardson number.

The profiles being considered in this study were obtained in several different ocean areas and at various times prior to 1978.

2.2 TRACKED DRIFTERS

The Lagrangian drifter data being examined by NRL are described in detail by Gordon and Greenewalt (1980). Thirteen drifters were deployed and tracked in a region

northwest of Bermuda (32^{o} 30'N to 34^{o} 00'N; 64^{o} 50'W to 66^{o} 20'W) during 16-23 September, 1979. Trajectories for ten of the drifters are treated in Gordon and Greenewalt (1980). Six of these were drogued within the surface mixed layer at a depth of 5 m; the remaining four were deployed below the base of the mixed layer (two at 45 m and two at 60 m). While these drifters were being tracked XBT profiles and standard meteorological observations were obtained.

The positions of the drifters were determined with a mean precision of .35 km using LORAN-C navigation. The time between consecutive sightings of an individual drifter ranged from .22 hr to 13.57 hr with a mean time interval of 4.36 hr. The intervening positions were determined by various interpolation schemes to provide a continuous trajectory for each drifter.

Drifter data such as these are best suited for an examination of such questions as the time evolution of the configuration of a scalar wake. For example, drifters that are deployed along a straight line simulate the tagged particles which define a wake. Of course the drifters do not respond perfectly to the movement of the water at drogue depth. However, to the extent that they do follow the water, their trajectories simulate the horizontal displacement from the initial wake configuration experienced by the various individual segments of the simulated wake.

The relative motions exhibited by drifters deployed in a cluster configuration at a specified depth are best suited to an examination of quantities defined in terms of horizontal gradients such as the vertical component of

vorticity, horizontal divergence, and horizontal distortion. Of course the scales over which the derivatives are computed continually change since they are determined by the drifter separations. The accuracy of the computed quantities is affected by the response of the drifters to the water movement and by the precision of the position determinations (i.e., .35 km).

Drifter data are not well suited to an examination of vertical gradients of velocity. This is consistent with the conclusions of Gordon and Greenewalt (1980). Plots of separation distance versus time for drifters drogued at 5 m, presented in their report, show that separation rates tend to increase with initial separation distance. This indicates that horizontal velocities are definitely not uniform in the horizontal direction. The same tendency is exhibited in similar plots for separation distances between drifters drogued at different depths. Hence the separation rates for these vertically separated drifter pairs are being contaminated and probably dominated by horizontal variations in the velocity field. Therefore vertically separated drifter pairs cannot be used to estimate vertical shear except when the drifters are in very close lateral proximity. Even then the vertical scale over which the shear can be computed is dictated by the vertical separation of the drogues.

2.3 SIMULTANEOUS DOPPLER SONAR AND EXPENDABLE CURRENT PROFILER DATA

Another velocity data set currently being examined by Hill, Okawa, and others at NRL consists of nearly simultaneous velocity profiles obtained with a modified

AMETEK/Straza Doppler shear profiler (DSP) and with Sippican expendable current profilers (XCP). These data were obtained near Bermuda during the fall of 1979 aboard the RV H. C. HAYES. The data were collected while the ship was underway at 5 to 6 knots.

2.3.1 Doppler Shear Profiler

Doppler sonar devices have been in existence for a number of years and have been used primarily by large ships, such as oil tankers, to monitor their velocity relative to the bottom during docking maneuvers. The device, which is mounted on the hull of the ship, transmits pulses of acoustic energy along four highly directional beams which are configured in what is referred to as the Janus configuration. That is, each beam is inclined 30 degrees relative to vertical with one pointed forward, one aft, one toward port, and one toward starboard. The transmitted pulses have a known frequency. If there is relative motion between the ship and the bottom, the acoustic energy scattered from the bottom will have a mean frequency which is different than that of the transmitted pulse. The frequency shifts, called Doppler shifts, monitored by the four beams (actually only three are necessary) specify the velocity of the ship relative to the bottom.

The acoustic signal need not penetrate to the bottom to be scattered. Much of the water column contains acoustic scatterers which may be either biological forms, suspended material, or possibly even turbulence. Consequently acoustic energy is being scattered to some extent

at every point along the beam path. By analyzing discrete segments of the return signal (called range gating), Doppler information can be obtained for discrete range intervals along each sonar beam. In this way relative velocities parallel to each beam can be determined for a series of discrete points along each beam. Several years ago this fact motivated scientists at Scripps Institution of Oceanography (SIO) and at the Engineering Development Laboratory of the National Oceanic and Atmospheric Administration (NOAA) to undertake the modification of existing Doppler sonar devices to test the feasibility of using these instruments for obtaining vertical profiles of horizontal velocity. Recently NRL has become involved. The modification and testing phase is progressing. Preliminary results at NRL, SIO, and elsewhere have been encouranging. Proposed modifications should make the device, now referred to as a Doppler shear profiler (DSP), increasingly useful.

Any three non-colinear components completely specify a vector quantity. Hence, if it can be assumed that three beams are measuring three different components of the same total velocity vector, then that vector is completely specified. The fourth beam would be redundant. This simplifying assumption becomes less tenable with increasing depth as the sonar beams diverge.

While high frequency transmissions offer the advantage of either more precise velocity determinations or better vertical resolution or both, they have the disadvantage of reduced range due to rapid signal attenuation. Since docking maneuvers usually occur in shallow water, signal attenuation for that application has historically not been a matter for concern.

The AMETEK/Straza system used by NRL emits a 300 KHz pulse with a duration of either 10, 20, or 30 ms. The data currently under examination were all obtained using a 10 ms pulse. The strength of the reflected signal decreases with range. The data acquisition system in use has a pre-set threshold below which the signal-to-noise ratio is considered unacceptably low. All Doppler data are stored, but only those with a signal strength above the threshold are used in subsequent velocity calculations. For a given range interval, a velocity can be computed if data is lost from no more than one beam. Otherwise, there is no velocity determination within that particular range interval for that particular set of pulses. Naturally the occurrence of data losses due to attenuation increases with depth. Even when the data are not lost, the uncertainty in the computed velocities increases with depth due to the decreasing signal-to-noise ratio and the increasing beam separation. Preliminary analysis of the NRL data set suggests that the effective depth of their DSP is between 100 and 130m. Hence the accessible depth range is from a few meters below the transmitter (say 10m) to about 100m. Fortunately, this is a depth range that is frequently missed by other velocity profiling devices.

There are various complications imposed by ship motion. One relates to ship attitude. As the ship rolls and pitches the coordinate system of the sonar beam array is continually changing its orientation with respect to earth coordinates. During the test aboard HAYES the vessel was equipped with inclinometers to monitor pitch and roll. This combined with the ship's heading monitored

by the ship's gyrocompass completely specified the ship's attitude. These data were used to transform the array coordinates into earth coordinates before any further processing was done. Vertical profiles of horizontal velocity were constructed by computing velocities for horizontal layers of ocean. This involved selecting the range interval along each beam path that most closely coincided with the horizontal layer under consideration. Of course, these range intervals almost never coincide exactly with the horizontal layer and this introduces additional uncertainty in the computed velocities and it tends to degrade the vertical resolution of the profile. A proposal under consideration is to use the instantaneous ship's attitude data to specify the range interval to be used in recording the return signal for each individual pulse.

Another complication is that the ship is responding (with an unknown response function) to accelerations being imposed on it by the medium that it is measuring, namely the ocean. Since the Doppler sonar device is being used to measure relative velocities between the ship and the water in various layers in the upper 100m, the ship motions of primary concern are those acting over scales smaller than 100m. That is, the ship response to surface waves is more important than its response to larger scale "mean" motions. During the HAYES test there were no accelerometers on the vessel, however, this is being proposed for future tests. Consequently velocity power spectra show large peaks at high frequencies which are due to the ship's response to surface waves. In the present analysis these motions are

being "filtered" out of the velocity records by averaging over 30 to 100 pulses. Since the system transmits a pulse once each .63 seconds, this process averages the data over 19 to 63 seconds.

Since the ship is underway at approximately 5 knots during the data collection, the averaging, which is intended to remove the high frequency oscillations due to surface waves, has the added effect of averaging in the horizontal direction. At 5 knots an average over 63 seconds corresponds to an average over 162 m. Hence the addition of accelerometers to the system should improve the temporal and horizontal resolution of the velocity data.

The vertical resolution of the velocity data is directly proportional to pulse duration. As noted earlier, the NRL data set was obtained using 10 ms pulses. This corresponds to a pulse length along the beam axis of approximately 15 m. Since the signal is 300 KHz, a single pulse contains approximately 3000 cycles with a wave length of 5 mm. If the return signal is examined in 5 ms increments, this would yield an estimate of velocity every 3.8 m along the beam. However, each of these estimates would be based on signals coming from a layer of water corresponding to a slant range interval of 7.5 m. The 7.5 m resolution along the beam translates to a 6.5 m resolution in the vertical. This estimate of resolution is optimistic since factors such as response time of the frequency tracking receiver and corrections for ship's attitude will degrade this resolution to at least 10 m.

Bob Hill estimates that the uncertainty in the relative velocities obtained so far may be as large as 5 cm s^{-1}. This precision might be substantially improved if the proposed modifications to the system are implemented. The velocity estimates could also be improved by increasing the pulse duration. This, however, would degrade the vertical resolution.

Testing at Scripps has led to other suggested modifications in design which are presently being implemented by AMETEK/Straza in a new version of their DSP (Lloyd Regier, personal communication). The new device will have only three sonar beams and will transmit at a frequency of 120 KHz rather than 300 KHz. This will extend the depth range of the instrument but will degrade the vertical resolution. Regier (SIO) is generally interested in examining larger vertical scales and deeper ranges than Hill (NRL).

It seems clear that the DSP, or some modification of it, has the potential to measure vertical variations in horizontal velocity within the upper layers of the ocean from a ship that is underway. However, it should be borne in mind that the full potential is even greater. For example, in its present configuration, the DSP can provide information on the variations of the vertical component of velocity. However, due to the noise levels in the existing data sets and the emphasis being placed on the horizontal component of velocity, this information is not being examined intensively at this time. It should also be noted that the acoustic beams can in principal be pointed in

any arbitrary direction. Hence the Doppler sonar technique is well suited to an examination of the velocity structure of the ocean as a function of angle. In particular it is one of the few techniques presently available for an examination of the small scale velocity structure in the horizontal direction as has been demonstrated by Pinkel (1979). In short, the Doppler sonar technique offers the potential for examination of the three-dimensional velocity structure of the upper ocean.

2.3.2 Expendable Current Profiler

The expendable current profiler (XCP) is being developed by Sippican Corporation in collaboration with Tom Sanford of the Applied Physics Laboratory of the University of Washington. The XCP is a free-fall probe which uses principles of geomagnetic induction to measure the horizontal component of velocity (relative to an unknown constant velocity) versus depth. It also measures temperature versus depth. Horizontal velocities can be measured with a repeatability of $\pm$ 1 cm s^{-1}. The filtered velocity profiles have a vertical resolution of 2 to 3 m (Tom Sanford, personal communication). As with many vertical profilers, the data from the upper 50 m is frequently lost because of transients. (In this case, magnetic interference from the ship's hull is also a factor). Reliable data can be obtained in the depth range between 50 m and 800 m. According to Tom Sanford the probe fall rate is approximately 4.75 m s^{-1}, but there is an uncertainty of about 10%. Hence a profile can be obtained in something under 3 minutes. The temperature sensor has different

circuitry than the standard Sippican XBT. The temperature data obtained by the XCP may be in error by as much as .5 to 1.0°C in absolute value. However, relative temperatures are believed to be accurate to within a few tenths of a degree (Tom Sanford, personal communication).

The fact that the XCP is expendable and can be deployed while underway make it an ideal tool for examination of horizontal variability in vertical velocity structure. Also, since it obtains a complete profile in under 3 minutes, it is well suited for high resolution time series mesurements.

2.3.3 Comparison of Doppler Shear Profiler and Expendable Current Profiler Data

During the fall 1979 field test, 50 to 60 XCP profiles were obtained in conjunction with the DSP measurements. To eliminate some of the near surface data loss due to interference from the ship, the XCP's were deployed remotely (using a timed release) after the ship had steamed several hundred meters away.

For comparison purposes the XCP and DSP profiles were matched in space. This is, each XCP profile sampled approximately the same water column as that sampled by the DSP approximately two minutes earlier. Of course, the XCP profile is a filtered version of instantaneous horizontal velocities measured along the vertical trajectory of the probe. The horizontal velocities obtained with the DSP, on the other hand, are derived by first assuming horizontal

homogeneity over the scale of the four-beam array, and then averaging over many pulses, which effectively averages in the horizontal direction along the ship's track. Hence, some differences between the profiles are to be expected.

The profile shapes agree reasonably well over scales of several tens of meters. Over smaller scales there are disagreements, but no consistent trends have been identified. The analysis is still in its preliminary stages. Continued analysis may reveal ways in which the two data sets can be brought into better agreement. In view of the sources of error already identified in the two different instruments, the agreement shown by the two data sets is encouraging.

2.3.4 Planned Comparison with Current Meter Data

During October of this year Lloyd Regier plans to obtain DSP data while steaming around a moored array containing eight near-surface current meters. The experiment, which will take place approximately 200 miles west of San Diego, is funded by the Office of Naval Research. The new version of the DSP being built by AMETEK/Straza for Regier will not be available in time for this experiment.

Section 3
CONCLUSIONS

While each of the various velocity measuring techniques discussed above provide important information, the opportunities to make direct comparisons are extremely limited because of the different measurement paths. With some qualifications related to instrument response (which affect the accessible range of frequencies and/or wave-numbers), data from the three vertical profiling instruments can be directly compared. High quality density profiles are available from both YVETTE and SCIMP so that Richardson number profiles are readily computed. To the extent that vertical density gradients can be estimated from vertical temperature gradients, the XCP can in principal provide Richardson number profiles. However, at present, the quality of the temperature data provided by the XCP is substantially inferior to the velocity data.

The DSP measures velocities parallel to the sonar beams. Horizontal velocities are inferred by assuming horizontal homogeneity of the velocity field over scales comparable to the beam array. To the extent that this assumption is true, some potentially useful comparisons of vertical profiles of horizontal velocities are possible. The DSP does not provide a density profile. Hence to compute Richardson number, the density profile would have to be measured independently. An independent measurement would introduce errors due to a space-time mismatch between the velocity and the density profile. In addition, if the ship

is underway the density profile would have to be obtained with an expendable probe, probably an XBT, which is a poor substitute for a CTD.

Finally, while the Lagrangian drifter data are very useful in the examination of some horizontal properties of the velocity field, they are essentially incompatible with the vertical profiler data sets. Furthermore, while some of the YVETTE and SCIMP profiles were obtained near Bermuda, they are separated in time from the NRL data sets by almost four years.

Section 4
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